OPERATIONAL PERFORMANCE AND NITRIFYING CHARACTERISTICS OF A HYDROLYTICALLY-ASSISTED EXTENDED AERATION PROCESS AT HIGH ORGANIC LOADINGS

By

KOMMU SURYANARAYANA MURTHY

Bachelor of Engineering

Osmania University

Hyderabad, India

1968

Submitted to the Faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the Degree of
MASTER OF SCIENCE
May, 1974

OPERATIONAL PERFORMANCE AND NITRIFYING CHARACTERISTICS OF A HYDROLYTICALLY-ASSISTED EXTENDED AERATION PROCESS AT HIGH ORGANIC LOADINGS

Thesis Approved:

G. D. Gaudy Jr.
Thesis Adviser

Richard N. DeSimone

Don F Kincannon

N N Durham
Dean of the Graduate College

ACKNOWLEDGMENTS

Every individual aspires to be associated for his growth with the foremost persons in the field of his liking. The joy of life is greatest when this aspiration is fulfilled. The author's heart is filled with such joy in expressing his deep sense of gratitude and thanks to Dr. A. F. Gaudy, Jr., who assumed the responsibility of thesis adviser and secured for him the financial assistance throughout his graduate study.

Special thanks are extended to Dr. Don F. Kincannon, Dr. Richard N. DeVries, Dr. E. T. Gaudy, and Dr. Joseph H. Sherrard for their help and encouragement. The friendship and cooperation of the author's graduate colleagues, Godlove, Marcangelli, Scott, Stover, Srinivasaraghavan, Saidi, Stall, Rawoof, Reddy, Maq, Roach, Little, Bentley, Saleh, and Randhawa are gratefully appreciated.

Srimati Lakshmi Suseela, the author's wife, Sandhya Lakshmi, his daughter, and Chandra Sekhar, his son, are lovingly acknowledged for their sacrifice and understanding.

There are many individuals who encouraged and helped the author in his academic and social life, and the author sincerely thanks them. Special thanks are due to Mrs. Grayce Wynd for her affection, friendship, and for her careful and accurate typing of this thesis.

This investigation was made possible in part through the graduate research assistance provided by the School of Civil Engineering. The author is grateful to the Graduate Advisory Committee for selecting him for a Graduate Excellence Award.

Dedicated to

my Mother and Father

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

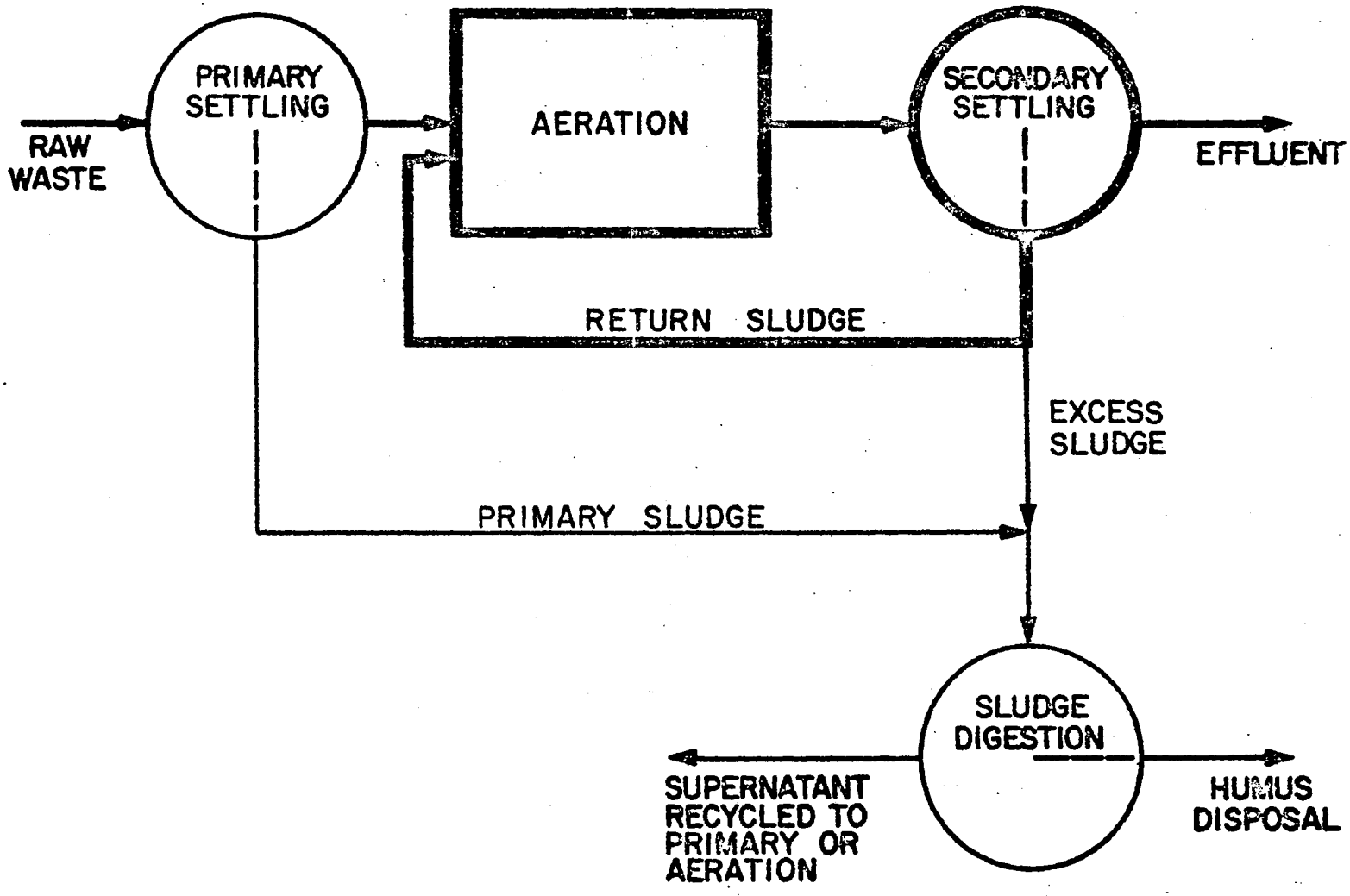
INTRODUCTION

There are many natural processes and engineered systems for improving waters which carry wastes. Wastewaters can be restored to usefulness by taking advantage of biological processes that go on in nature. Research activities on the important "secondary" treatment in water pollution control have resulted in various modifications of the widely used conventional activated sludge process. The extended aeration or total oxidation process is one such economical modification which has been used increasingly because of its simplicity in operation, low cost in maintenance, and its capacity to withstand various environmental changes. Figure 1 shows a flow diagram of a conventional activated sludge process and the extended aeration modification.

Increasing attention is being given to the total oxidation process because of its easy applicability to the waste treatment, especially in small sized plants where wastewater is not produced continuously, thereby a continuous source of inflowing nutrients is not available to supply the metabolic needs of aerobic microbial life. Consequently, the number of extended aeration plants has increased to an appreciable number, and their popularity is still increasing.

A great deal of research has been conducted, and the theory of total oxidation has been given a fair trial in many respects. Bench-scale extended aeration pilot plant studies were operated at Oklahoma

Figure 1. Comparison of the Extended Aeration and Conventional Activated Sludge Process. (For the extended aeration process, only the position of the diagram shown in heavy lines is required.)


PRIMARY
SETTLING
AERATION
SECONDARY
SETTLING
RAW
WASTE
EFFLUENT
RETURN SLUDGE
EXCESS
SLUDGE
PRIMARY SLUDGE
SLUDGE
DIGESTION
SUPERNATANT
RECYCLED TO
PRIMARY OR
AERATION
HUMUS
DISPOSAL

State University by Gaudy and his co-workers for nearly ten years (1)(2)(3)(4). During their studies, the practical evidence has indicated that such a system can be operated with an appreciable biochemical efficiency without solids accumulation, without practicing sludge wasting. From these studies, an extended aeration process modification has been developed which provides for a high degree of engineering control of solids concentration. This improvement is known as the "hydrolytic assist." As water quality standards and stream standards have become increasingly more stringent, it has become imperative that waste water treatment facilities be designed employing new innovative design concepts which appear to be economically feasible. Modern-day environmental engineers are called on to not only design appropriate pollution control facilities, but also to devise control schemes for easy refined operation of such facilities. The "hydrolytic assist" may offer increased operational control of the process.

One of the characteristics of the extended aeration process is that it often provides a highly nitrified effluent. The removal of nitrogen compounds from wastewater has created much accelerated interest, because the discharge of these contaminants is manifested in the growth of algae and aquatic plants. Essential steps are necessary to control the discharge of these contaminants, otherwise over-fertilization will continue to increase--especially with the multiple re-use of water. The natural process of nutrient enrichment of the watershed is known as "eutrophication." The rate of eutrophication can reach critical levels in a short period of time if not attended, and thus become a serious problem for an environmental engineer. Hitherto in the design of treatment plants, economy and removal of organic matter were the main

criteria, and removal of nitrogen was not given serious consideration. But of late, many researchers as well as field personnel are aware that removal of ammonia nitrogen is an essential item to be considered because its presence can contribute to development of various problems in receiving streams--such as eutrophication, reduction in dissolved oxygen, toxicity to fish, and formation of chloramines if the effluent is chlorinated.

Water quality coordinating committees have suggested guidelines to control pollution and to maintain the best quality which will result in an equitable balance of social and economic benefit to the state. Therefore, preventive measures are necessary to overcome these undesirable water quality characteristics. The important forms of nitrogen in wastewater are organic nitrogen (such as proteins and amines), ammonia, nitrite, and nitrates. Nitrogen in wastewater may be removed by several methods (5):

1. biological unit processes: a) algae harvesting, b) nitrification and denitrification, c) bacterial assimilation
2. ammonia stripping
3. chlorination
4. treatment of digester supernatant
5. ion exchange
6. land application
7. reverse osmosis
8. carbon adsorption
9. chemical precipitation
10. electrodialysis

Biological nitrification in the activated sludge process has been

given wide attention in an attempt to utilize the existing facilities. During nitrification, a series of reactions convert organic and ammonia nitrogen to nitrate. For this bacterial process, oxygen is drawn from available resources to allow the reactions to proceed.

Despite the number of extensive studies reported previously regarding extended aeration, there is a lack of research in the investigation of removal of nitrogen at various organic loadings. It would be wise from an engineering standpoint to determine for what organic loadings nitrification would be possible.

The aim of this research can be generally stated as follows:

1. To provide more information for design and operational procedures pertinent to the extended aeration process incorporating the "hydrolytic assist."

2. To investigate the possibility of nitrification in the extended aeration process to achieve nitrified effluents for various higher organic loadings.

3. To obtain necessary operational data from predetermined withdrawal schedules during hydrolysis to determine the feasibility of the "hydrolytic assist" as an engineering control.

CHAPTER II

LITERATURE REVIEW

Extended Aeration

Extended aeration treatment is one of the various modifications to the conventional activated sludge processes. Porges and his co-workers (6)(7)(8) were the first investigators to report the concept and theory of total oxidation. They concluded that during high rates of endogenous respiration, microorganisms oxidize their own tissue and do not allow sludge to accumulate. They also reported that a portion of the soluble organic dairy waste they employed as substrate was converted to cell material and later auto-oxidized. Thayer (9)(10) designed plants with detention times varying from 36 to 40 hours in the aeration tank, and two to four hours in the settling tank for treating milk wastes. They obtained 96 percent purification efficiency.

Symons and McKinney (11) from their studies on soluble organic substrates concluded that the accumulated material which was observed to be mostly extracellular polysaccharides was resistant to biological degradation. Thus, they put forth their opinion that if no sludge was wasted, the extended aeration process could not perform successfully.

A series of experiments with different loadings was conducted by Busch and Myrick (12) to determine the limitation of the total oxidation process. From these studies they came to a conclusion that total oxidation is neither theoretically nor practically attainable, and a

buildup of biological solids is inevitable.

The report of McCarty and Broderson (13) is particularly interesting. They expected that nitrification in the aeration tank would cause false values for BOD removal efficiency as well as increase the possibilities for a rising sludge in the settling tank.

Long-term studies of Washington, Hetling, and Rao (14) showed that the system did not reach a steady state condition, but demonstrated periods of increasing biological solids as well as periods of decreasing biological solids. They felt that the period of decreasing solids was due to adaptation of an organism to the accumulated sludge.

Sawyer (15) presented a few guidelines, which include an aeration time of 24 hours, a BOD loading of about 15 lbs BOD/day/1000 cu ft and 5000 to 8000 mg/l biological solids concentration, for satisfactory operation of the extended aeration process.

After noting the controversy regarding the feasibility of achieving oxidation through the extended aeration process, Gaudy and his coworkers conducted long-term systematic experimental work and concluded that the concept of total oxidation was consistent with sound microbiological theory. Ramanathan, Gaudy, and Ragthaidee (1) in their studies on shock loading (500 to 2500 mg/l glucose) showed that there was considerable operational stability of the extended aeration process under shock conditions. During another series of experiments, Gaudy, Ramanathan, Yang, and DeGeare (2) after nearly two years of study, concluded that an extended aeration pilot plant can be operated with good biochemical efficiency without sludge wasting and continual solids accumulation. Also, investigations conducted by Obayashi and Gaudy provided direct evidence that extracellular polysaccharide serves as an oxidizable

carbon source for growth of microorganisms.

"Hydrolytic Assist"

The "hydrolytic assist" is an engineering modification to the process to accelerate biological autodigestion. In the pilot plant studies previously cited (2) it was observed that at times, the cell concentration became so great that it caused settling problems in the clarification chamber and loss of biological solids in the effluent. To aid biological autodigestion, an engineering solution to this problem was suggested by Gaudy, Obayashi, and Yang (3) known as the "hydrolytic assist." They suggested a rather innovative process modification for the extended aeration activated sludge process which incorporated periodic chemical hydrolysis for control of sludge concentration.

Yang and Gaudy (16) recently reported the results of pilot plant studies in which the "hydrolytic assist" was employed. The inflowing substrate loading was 300 mg/l glucose, and 900 ml sludge were withdrawn weekly for hydrolysis and refeeding to the aeration chamber over the succeeding weekly period. The conditions of hydrolysis were the same as those previously recommended by Gaudy, et al. (16). The pH was adjusted to 1.0 and the sludge was autoclaved for five hours at 121^{o}C and 15 psi. The hydrolyzed sludge was then neutralized and fed back to the aeration chamber along with the synthetic waste. The results indicated that an extended aeration activated sludge process could be successfully operated using the "hydrolytic assist." Biological concentration in the system was controlled at a pre-determined level, and effluent quality was very good. Also, the system produced a highly nitrified effluent.

In their experiments on the process suggested by Gaudy and his co-workers, Patterson and Tarasingh (17) reported that adjustment of pH 1.0 plus heat treatment was an effective method of liquefying high molecular weight cellular components. Solids reduction of 60 to 70 percent was observed with a residual of 30 to 40 percent non-solubilized sludge solids.

Bulking Sludge

Because of the high biological solids concentration in extended aeration processes, some discussion of sludge bulking seems warranted. One of the most common causes of bulking is the proliferation of filamentous growth. Heukelekian and Weisberg (18) concluded that zoogleal bulking and filamentous bulking were completely different phenomena. The activated sludge could have a high sludge volume index (SVI) without being very filamentous. Finstein and Heukelekian (19) reported that in some activated sludge processes, the SVI of the sludge produced was directly proportional to the number and length of filaments projecting from the particles.

Farquhar and Boyle (20) developed techniques for identifying filamentous organisms at sludge plants. Most of the organisms commonly associated with the bulking are found to be Sphaerotilus and Thiothrix. Generally, area:volume ratio is higher for free-growing filamentous organisms than for spherical aerobes. On this basis, Pipes (21) suggested the filamentous organisms have a metabolic advantage in activated sludge reactors with high soluble organic substrate, low dissolved oxygen, or low nutrient condition. Sphaerotilus, Beggiatoa, Bacillus, and Geotricum cause filamentous bulking in activated sludge generally. He

also presented some useful guidelines to discover the cause of bulking. Elizabeth Gaudy and Wolfe (22) found that Sphaerotilus can produce large quantities of extracellular polysaccharide, and observed formation of floc particles in a pure culture. Charles and his co-workers (23) through their laboratory tests, showed that the addition of H_2O_2 to the sludge recycle during Sphaerotilus filamentous bulking in an activated sludge process reduced the SVI to controllable levels.

The Nitrogen Cycle and Water Pollution

Extended aeration processes usually provide for a high degree of nitrification, thus some discussion of the various forms of nitrogen in the waste should prove helpful.

Natural sources that contribute significant quantities of nitrogen compounds include domestic and industrial wastes, runoff from agricultural land, animal waste, and urban runoff. Biologists and chemists followed various nutrient cycles and quantified their importance and sources, while pollution control engineers have turned their efforts to development of methods of removing nutrients from wastewaters before they enter a waterway. Clean, natural waters rarely contain more than 0.1 ppm ammonia nitrogen, while community sewages commonly contain 15 to 50 mg/l (NH_3-N). Nitrification is brought about, in the main, by the microorganisms Nitrosomonas and Nitrobacter. Present biotechnology recommends removal or treatment of unoxidized nitrogen in addition to chemical oxygen-demanding organic matter and suspended solids.

Sawyer and his co-workers (24) during their laboratory studies felt that the rate of nitrification depends on temperature and pH, and optimum pH was found to be 8.4. They reported that ammonia nitrogen

concentration of less than 60 mg/l did not inhibit nitrification, and concluded that the time required for nitrification is directly proportional to the amount of nitrifiers present in the system. They also found that the DO content in the nitrification tank is very important; however, there are differences of opinion regarding the governing factors.

Jerzy (25) reported that normally, nitrification in an activated sludge process may be attributed to loading parameters. He tried to explain the observed nitrification inhibition by means of the mixed liquor pH values. Beckman and his co-workers (26) from their studies concluded that biological nitrification depends on temperature, and optimum temperature was found to be 18.3°C (65°F). They reported that F:M ratio of 0.25 or less would be optimum. The important contradicting observation that was noticed was that the pH had no significant influence on the rate of ammonia removal.

According to Downing's discussion (27) on the effect of pH value on nitrification in the activated sludge process, the optimum range of pH values for Nitrosomonas was found to be between pH 7 and pH 9, and for Nitrobacter, in the range pH 7.0 to 8.6.

Ammonium and nitrite are oxidized according to the following stoichiometry (28):

$$NH_4 + \frac{3}{2} O_2 \xrightarrow{\text{Nitrosomonas}} NO_2^- + 2H^+ + H_2O$$

$$NO_2^- + \frac{1}{2} O_2 \xrightarrow{\text{Nitrobacter}} NO_3^-$$

These reactions furnish energy for the growth of the nitrifying bacteria during which some of the nitrogen is assimilated into

bacterial protoplasm, carbon dioxide being used as a source of cell carbon. The equations given below show the nitrogen required for growth and energy for Nitrosomonas and Nitrobacter (28):

Nitrosomonas

$$55\ NH_4 + 5\ CO_2 + 76\ O_2 \longrightarrow C_5H_7O_2N + 54\ NO_2^- + 52\ H_2O + 109\ H^+$$

Nitrobacter

$$400\ NO_2^- + 5\ CO_2 + NH_4 + 195\ O_2 + 2\ H_2O \longrightarrow C_5H_7O_2N + 400\ NO_3^- + H^+$$

Excellent nitrifying characteristics in an extended aeration process operated with the "hydrolytic assist" were reported by Gaudy and Yang (29).

Drews and co-workers (30) during their studies on the "orbal" extended aeration process reported that the effluent quality was exceptionally good, and high nitrogen dissipation rates were observed for low BOD loadings even though there were low DO concentrations, usually less than one mg/l (or 0 mg/l) in the channels. Various investigators also reported production of highly nitrified effluents at extended aeration plants (31).

CHAPTER III

MATERIALS AND METHODS

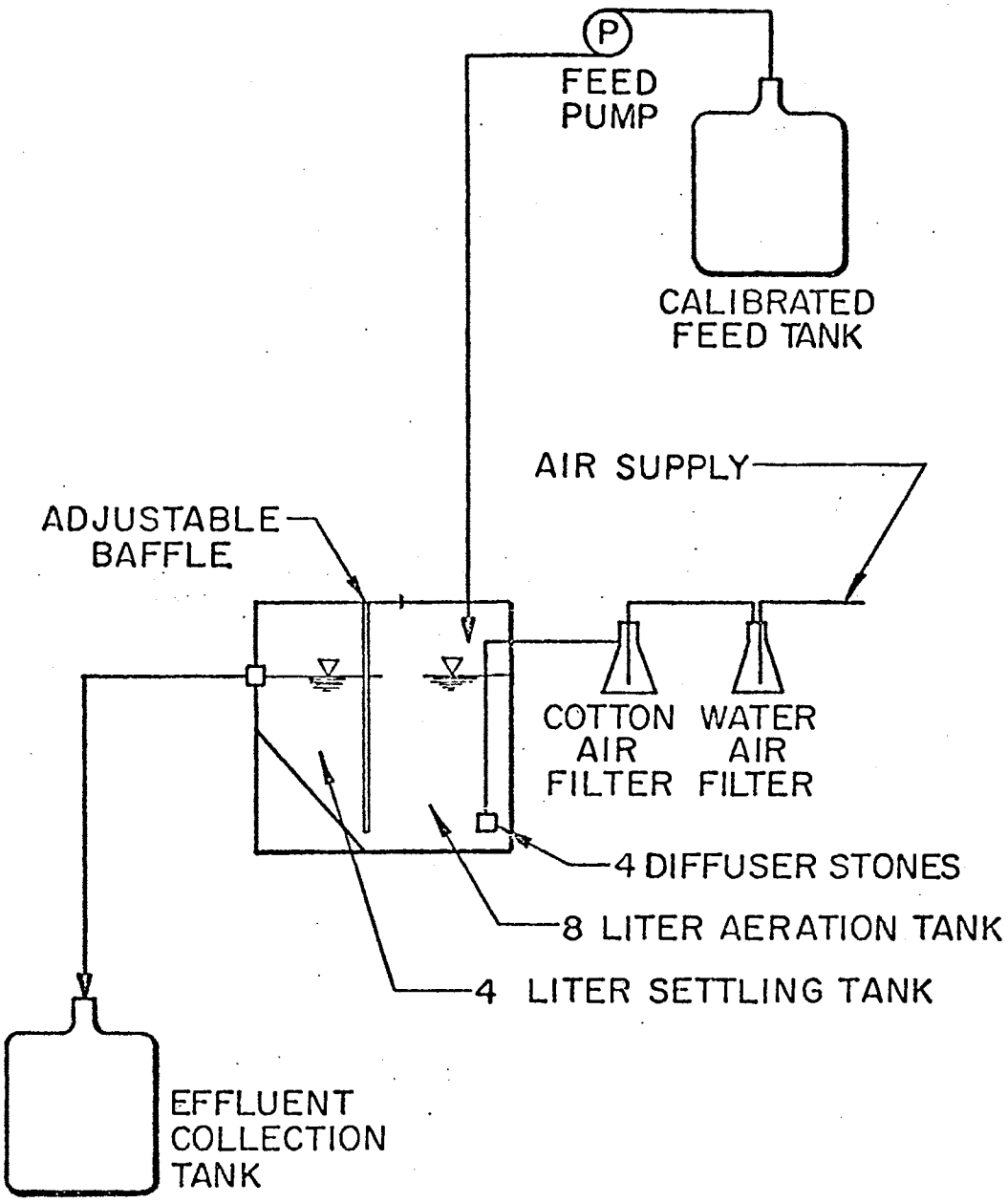
To study the performance and the nitrifying characteristics of the effluent of the activated sludge process, a bench-scale extended aeration pilot plant was operated under closely controlled conditions. For ease of presentation, the experimental laboratory apparatus, the feed solution, initial startup, daily protocol, analytical procedures, and methods of data analysis used to carry out the objects of this study are described separately.

Experimental Laboratory Apparatus

A schematic diagram of the pilot plant with other apparatus used in this experimental investigation is shown in Figure 2. A 12-liter plexiglass reactor with internal recycle of bacterial cells served as the aeration tank and secondary clarifier. An adjustable baffle was used to separate the aeration and settling compartments. The total volume of the unit was 12 liters; the aeration chamber and clarifier volume were eight and four liters, respectively. A feed rate of 12 liters/day (24 hours) was set to provide a hydraulic detention time of 16 hours in the aeration chamber, and eight hours in the settling tank.

Air was supplied through four porous diffuser stones at a total rate of approximately 2000 cc/min/l. This compressed air was not only adequate to provide thorough and complete mixing and supply sufficient

Figure 2. Continuous Flow Extended Aeration Pilot Plant


P
FEED PUMP
CALIBRATED FEED TANK
AIR SUPPLY
ADJUSTABLE BAFFLE
COTTON AIR FILTER
WATER AIR FILTER
4 DIFFUSER STONES
8 LITER AERATION TANK
4 LITER SETTLING TANK
EFFLUENT COLLECTION TANK

oxygen for the microorganisms, but also created required movement to recycle solids from the settling tank compartment. To protect the biological system from oil contamination which is occasionally present in the compressed air supply, two filters--a cotton filter followed by a water filter--were placed in the line, as shown in Figure 2. Temperature was maintained at $23 \pm 2^{o}C$.

A Milton Roy dual positive displacement pump (Mini-pump Model MM2-B-96R) was used to provide a continuous flow of feed solution to the aeration tank. The feed lines were disinfected by pumping one percent solution of Clorox for at least one hour, followed by tap water to cleanse the lines of the disinfectant. One of the feed lines was being disinfected while the other was being used. Pumping rates were checked periodically by means of a graduated cylinder and stopwatch.

Feed Composition

Chemical composition of the synthetic waste used in this study is listed in Tables I, II, and III. The influent substrate concentrations were 1000, 1500, and 2000 mg/l glucose + hydrolysate which resulted in organic loadings of approximately 100, 150, and 200 lbs COD/1000 cu ft aeration capacity (on the basis of aeration tank volume), or 66, 100, and 133 lbs COD/1000 cu ft on the basis of the total volume of the system during continuous flow operations. The feed pH was maintained at approximately 7.3, and considerable care was exercised in the preparation of phosphate buffer solution. The effective pH of a buffer solution made from phosphate salts was determined by the ratio of their molar concentrations, according to the following equation (32):

$$pH = pK_2 + \log \frac{[K_2HPO_4]}{[KH_2PO_4]}$$

TABLE I

CONSTITUENTS IN THE FEED DURING OPERATION WITH SUBSTRATE LOADING CONSISTING OF 1000 mg/l GLUCOSE AND VARIABLE AMOUNTS OF SLUDGE HYDROLYSATE

Glucose	1000 mg/l
Hydrolysate COD	40 mg-100 mg/l
$(NH_4)_2SO_4$	500 mg/l
$MgSO_4 \cdot 7H_2O$	100 mg/l
$FeCl_3 \cdot 6H_2O$	0.5 mg/l
$CaCl_2$	7.5 mg/l
$MnSO_4 \cdot H_2O$	10 mg/l
Phosphate buffer 1.0 M, pH 7.6	
$(KH_2PO_4 + K_2HPO_4)$	10-30 ml/l
Tap water	100 ml/l
Distilled water	to volume

TABLE II

CONSTITUENTS IN THE FEED DURING OPERATION WITH SUBSTRATE LOADING CONSISTING OF 1500 mg/l GLUCOSE AND VARIABLE AMOUNTS OF SLUDGE HYDROLYSATE

Glucose	1500 mg/l
Hydrolysate COD	100-150 mg/l
$(NH_4)_2SO_4$	750 mg/l
$MgSO_4 \cdot 7H_2O$	150 mg/l
$FeCl_3 \cdot 6H_2O$	0.75 mg/l
$CaCl_2$	11.25 mg/l
$MnSO_4 \cdot H_2O$	15 mg/l
Phosphate buffer 1.0 M, pH 7.6	
$(KH_2PO_4 + K_2HPO_4)$	15-45 ml/l
Tap water	150 ml/l
Distilled water	to volume

TABLE III

CONSTITUENTS IN THE FEED DURING OPERATION WITH SUBSTRATE LOADING CONSISTING OF 2000 mg/l GLUCOSE AND VARIABLE AMOUNTS OF SLUDGE HYDROLYSATE

Glucose	2000 mg/l
Hydrolysate COD	150-200 mg/l
$(NH_4)_2SO_4$	1000 mg/l
$MgSO_4 \cdot 7H_2O$	200 mg/l
$FeCl_3 \cdot 6H_2O$	1.0 mg/l
$CaCl_2$	15 mg/l
$MnSO_4 \cdot H_2O$	20 mg/l
Phosphate buffer, 1.0 M, pH 7.6	
$(KH_2PO_4 + K_2HPO_4)$	20-60 ml/l
Tap water	200 ml/l
Distilled water	to volume

Initial Startup

An initial seed of microorganisms was taken from a well-operating laboratory extended aeration activated sludge system similar to the one previously described. The original inoculum for this activated sludge was obtained from the primary clarifier effluent of the municipal sewage treatment plant at Stillwater, Oklahoma. The unit was operated on a batch basis until the solids concentration had built up to approximately 2500 mg/l. The organisms were batch-fed with 1000 mg/l substrate concentration on a once-a-day basis for three weeks. One-third of the total volume was wasted from the supernatant after allowing the cells to settle for an hour each day, and again made up to the volume (12 liters) with distilled water.

When the solids concentration reached approximately 2500 mg/l, the unit was switched to continuous flow operating conditions. The continuous extended aeration pilot plant used in this study was similar to that used by David Scott (33) in his studies on the extended aeration activated sludge process with the "hydrolytic assist." The parameters which were monitored daily are shown in Table IV.

"Hydrolytic Assist"

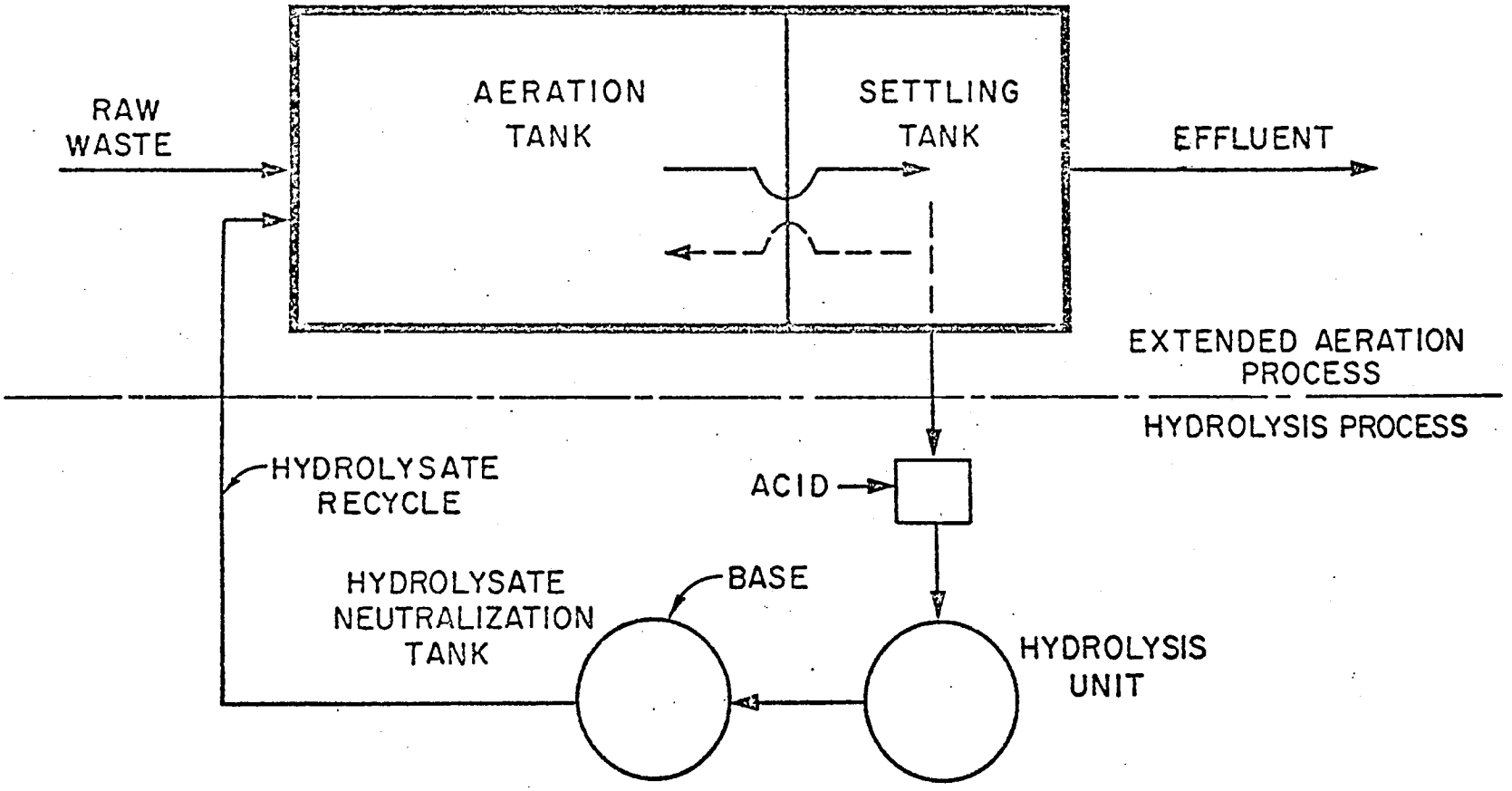
The typical flow diagram for the "hydrolytic assist" is shown in the lower portion of Figure 3. The hydrolysate was prepared by taking 90 ml of settled sludge per week from the settling compartment of the pilot plant. The pH of the removed sludge was lowered to pH 1.0 with concentrated sulfuric acid (N 36). The sludge was then placed in an autoclave for five hours at 15 psi and 121^{o}C. The hydrolyzed sludge was then neutralized to pH 7 with potassium hydroxide (N 10) and fed

TABLE IV

PARAMETERS MONITORED DAILY

I.	Feed
	A. Chemical Oxygen Demand
	B. pH
II.	Filtered Effluent
	A. Chemical Oxygen Demand
	B. Total NH_3-N Concentration
	C. Total NO_2-N Concentration
	D. Total NO_3-N Concentration
III.	Unfiltered Effluent
	A. Chemical Oxygen Demand
	B. Suspended Solids Concentration
IV.	Biological Reactor
	A. Total System Microorganism Concentration
	B. Dissolved Oxygen in the Aeration Basin
	C. Dissolved Oxygen in the Settling Tank
	D. pH

Figure 3. Extended Aeration Activated Sludge Process Incorporating Chemical Hydrolysis for Control of Sludge Concentration


RAW
WASTE
AERATION
TANK
SETTLING
TANK
EFFLUENT
EXTENDED AERATION
PROCESS
HYDROLYSIS PROCESS
HYDROLYSATE
RECYCLE
ACID
HYDROLYSATE
NEUTRALIZATION
TANK
BASE
HYDROLYSIS
UNIT

along with glucose minimal medium to the system. This hydrolysate was equally divided into seven parts by volume, and was fed to the system at the rate of one part per day. This normally increased the organic loading by approximately 100 to 300 mg/l, depending upon the hydrolysate concentration.

Daily Protocol

Every effort was made to develop operating procedures leading to efficient and accurate collection of data. Table IV shows the parameters which were monitored and recorded daily. Twenty-ml samples of the fresh feed (S_i) and the supernatant (S_e) were removed for the chemical oxygen demand (COD) determination. A 50-ml effluent sample was collected in a graduated cylinder for the determination of effluent solids concentration (X_e). From this filtrate, a 20-ml sample was removed for the determination of chemical oxygen demand (S_e'FIL); the remaining effluent was placed in a glass vial and frozen for later determination of NH_3-N, NO_2-N, and NO_3-N.

Every day before changing the feed, the effluent line was plugged and the feed was momentarily shut off. The dividing baffle was then lifted and the contents of the total system were allowed to mix completely. Then a 25-ml sample was pipetted from the unit for determination of solids concentration (X) in the total system, and the dividing baffle was again replaced. The settling chamber effluent plug was removed and the feed restarted. The unit was then back on continuous flow operation. This procedure allowed a direct assessment of the course of changes in solids concentration in the total system. Feed, mixed liquor, and effluent were checked for pH.

The concentrations of dissolved oxygen in the aeration tank and settling tank were measured by a Weston and Stack oxygen analyzer. A Precision Scientific galvanic cell oxygen analyzer was also used occasionally to measure the dissolved oxygen in accordance with the procedures given in the operating instructions supplied with the instrument (34).

Analytical Procedures

In this investigation, the chemical oxygen demand, biological solids concentration, NH_3-N, NO_2-N, and NO_3-N concentrations, pH, and dissolved oxygen were monitored daily. The following is a brief description of the methods and equipment used to measure these parameters:

Chemical Oxygen Demand

Chemical oxygen demand determinations were made in accordance with Standard Methods (35).

Biological Solids Concentration

The concentration of the biological solids were determined by filtering the appropriate volume through membrane filters (0.45μ pore size, (Millipore Filter Corp., Bedford, Mass.). The filter pads were placed in light weight aluminum tare pans and dried at 103°C in a drying oven for two hours. Then the filter pads were cooled to room temperature in a calcium carbonate desiccator and the initial weights of the pans were determined. All weights were obtained by using a Gram-ATIC balance (Fisher Scientific Company). Known volumes of samples were centrifuged with a Ser-Vall Superspeed centrifuge type SS-1A (Ivan Sorvall, Inc.)

for five to ten minutes. Then these centrifuged samples were filtered with the aid of a vacuum pump. The supernatant from the centrifuge sample was filtered first; the pellet of solids which was formed was removed with the aid of a spatula and placed on the filter. Filtrate samples were taken at this point for COD determination. The centrifuge tubes were carefully washed in distilled water to remove any solids particles that might have adhered to the sides of the tubes. After filtration, the pans were replaced in the drying oven for two hours at 103°C, cooled in the calcium carbonate desiccator, and weighed to determine the biological solids concentration.

Dissolved Oxygen

Dissolved oxygen concentration was monitored both in the aeration chamber and settling tank electrometrically, as previously described.

Microscopic Examination

Periodic microscopic analyses of the aeration tank mixed liquor were performed. Predominant morphological forms of microbes were recorded.

Nitrogen

Ammonia nitrogen was determined by a method developed by Niss and described by Ecker and Lockhart (36).

Nitrogen (nitrite) determinations were made in accordance with Standard Methods (35). Nitrogen (nitrate) NO_3-N was determined by the Brucine method (tentative) as outlined in Standard Methods (35).

pH

The pH was determined by the use of a Beckman Expandomatic SS-2 pH meter. Periodic standardization of the meter at pH values of 4, 7, and 10.0 ensured accuracy of the readings.

Methods of Data Analysis

Treatment purification or chemical oxygen demand removal efficiencies were calculated according to these expressions:

a) Efficiency based on filtrate COD:

$$E = \frac{100\left[S_i - S_e(FIL)\right]}{S_i}$$

where

E = COD removal efficiency, percent

S_i = influent substrate concentration, mg/l

S_e (FIL) = filtered effluent substrate concentration, mg/l

b) Efficiency based on unfiltered effluent or supernatant:

$$E_s = \frac{100(S_i - S_e)}{S_i}$$

where

E_s = COD removal efficiency based on supernatant, percent

S_i = influent substrate concentration, mg/l

S_e = supernatant substrate concentration, mg/l

CHAPTER IV

RESULTS

The reactor was inoculated with effluent from the primary clarifier of the municipal sewage treatment plant of Stillwater, Oklahoma, and after three weeks of "batch" development of solids to a concentration of 2500 mg/l on daily feedings of 1000 mg/l glucose plus mineral salts, the unit was changed over to continuous flow on September 7, 1973, and the 1000 mg/l substrate concentration in the feed continued.

This pilot plant operation was started with a view to investigate the possibility of nitrification in the extended aeration process and to determine for what organic loadings nitrification would be possible in such a process incorporating the "hydrolytic assist." Fortunately--or unfortunately, as the case may be--there was slight indication of bulking sludge during the ninth and tenth days after starting continuous operation; by that time the biological solids concentration increased to 5000 mg/l. Thus, early investigational efforts were directed toward solving the bulking problem.

The results obtained during this investigation are presented in four phases in the following order: First, studies were performed to test the effectiveness of the "hydrolytic assist" process as a means of controlling bulking sludge essentially by a change in species predominance. The second, third, and fourth phases present information on the operational performance and nitrifying characteristics of the extended

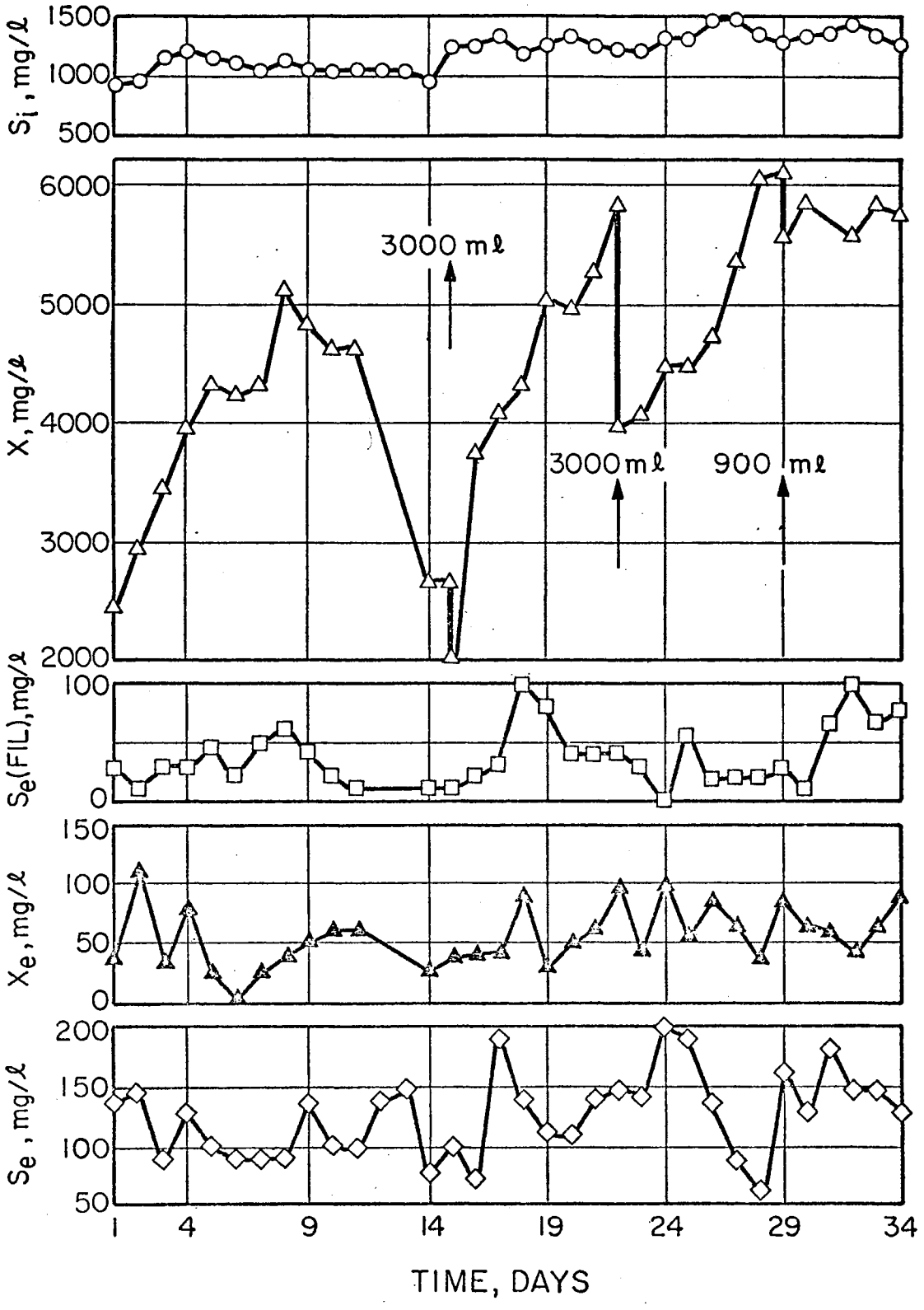
aeration process incorporating periodic "chemical assists" while growing on 1000 mg/l, 1500 mg/l, and 2000 mg/l of glucose + hydrolysate as carbon source (in accordance with Tables I, II, and III).

Phase I

Studies to Test the Effectiveness of the "Hydrolytic Assist" Process as a Means of Overcoming Bulking Sludge

On September 15th (day 9), microscopic examination of wet mounts from the settling tank revealed the presence of filamentous microorganisms. The biological solids concentration in the total system was 5000 mg/l. The pH in the aeration tank was 7.1. Very poor settling in the clarifier and escape of solids in the effluent were noticed, but there was very good purification efficiency of 98.4 percent based on filtrate COD. Previous studies (33) had indicated a possibility that the "hydrolytic assist" could be used to help bring about a change in the population from filamentous microorganisms to other more flocculatable species in the heterogeneous populations. In order to investigate this possibility in the present study, one-fourth of the total volume of the system (3000 ml) was withdrawn and subjected to acid hydrolysis (day 15, Figure 4). The solids concentration at the time of withdrawal had dropped, because of poor settling, to 2636 mg/l and decreased to 1970 mg/l because of withdrawal of 3000 ml of sludge. The neutralized hydrolysate was fed back to the system along with 1000 mg/l glucose at the rate of 1/7th volume of hydrolysate per day during the subsequent week (Figure 4). Microscopic examination of the hydrolysate indicated the absence of filaments. Again on the 22nd day, 3000 ml of sludge was

Figure 4. Performance Characteristics of a Hydrolytically-Assisted Extended Aeration Process Pilot Plant From Day one to Day 34 of Operation


S_i, mg/ℓ
1500
1000
500
X, mg/ℓ
6000
5000
4000
3000
2000
3000 mℓ
3000 mℓ
900 mℓ
S_e(FIL), mg/ℓ
100
0
X_e, mg/ℓ
150
100
50
0
S_e, mg/ℓ
200
150
100
50
1
4
9
14
19
24
29
34
TIME, DAYS

withdrawn from the final clarifier. At the end of this withdrawal period, the mixed liquor suspended solids in the unit was reduced from 5800 mg/l to 3900 mg/l. The withdrawn sludge was hydrolyzed, neutralized, and fed back to the system along with 1000 mg/l glucose. One of the methods for control of non-settling sludge previously found to be useful in other studies in our laboratories (33)(37) is through the addition of chemical flocculants. Therefore, beginning on day 15, the system also received periodic slug doses of ferric chloride. This caused no effect on the purification efficiency as measured by filtrate COD, but there was a beneficial effect on sludge settleability and compactness of the sludge in the clarifier. Many filamentous organisms are aerobic, while most of the bacteria are facultative and can exist for extended periods of time without oxygen. It has been suggested in the literature that anaerobic conditions for a short period of time may eliminate the growth of filament (38). To facilitate anaerobic environment, the air supply was discontineued for four hours on days 15 and 17. However, it was felt that such a procedure could do more harm to the system as a whole, and this practice was discontinued.

By day 30, microscopic examination revealed considerably reduced amounts of filamentous organisms and the presence of many protozoa in the mixed liquor. Also there was a significant increase in biological solids concentration (5900 mg/l); i.e., the sludge was being retained in the system because it was now settling in the clarifier. By the end of the Phase I operation, there was a pronounced decrease in the amount of filamentous forms, and those which were present appeared to be very short in length.

During this phase of operation, NH_3-N, NO_2-N, and NO_3-N of the

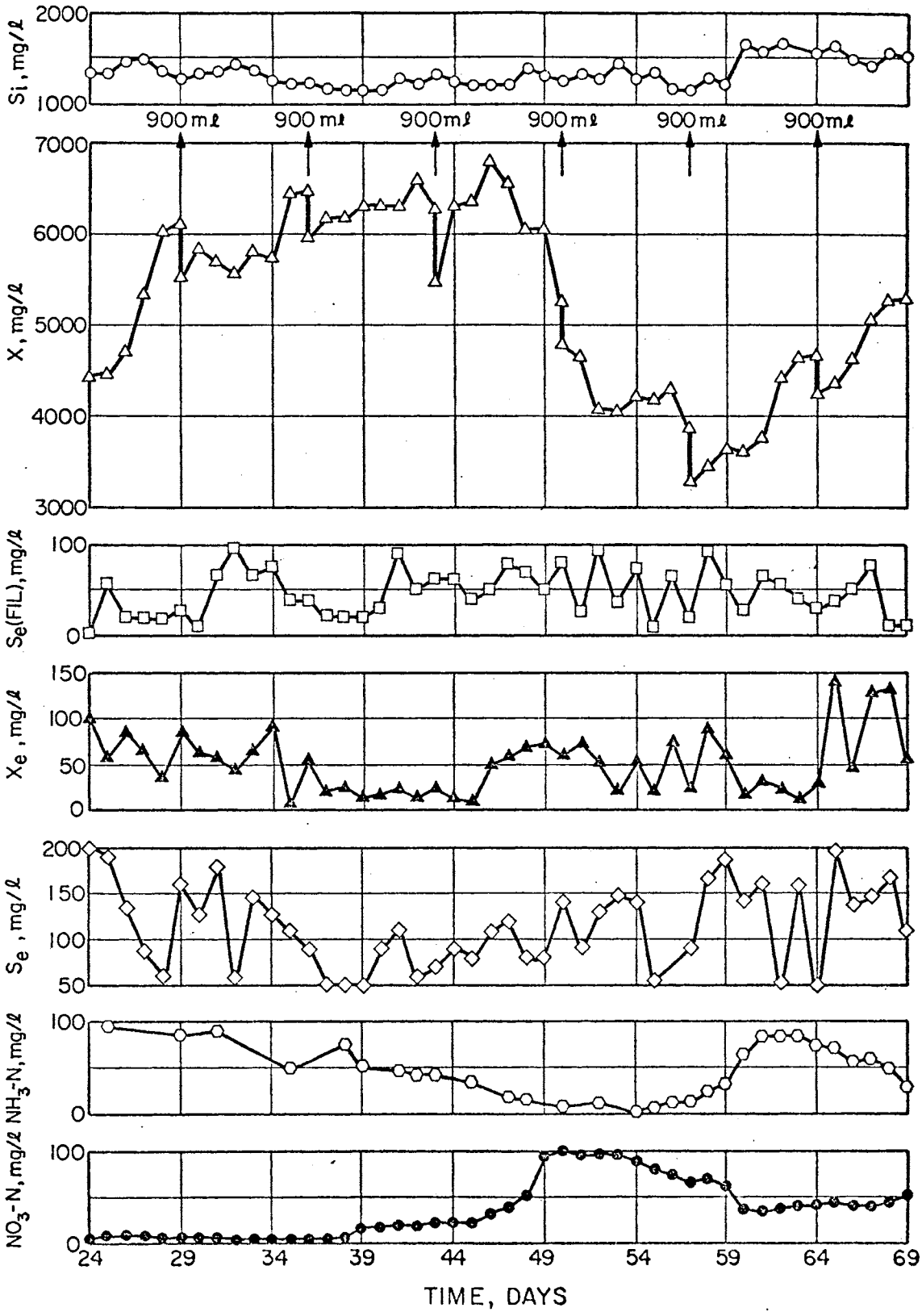
pilot plant effluent were determined periodically. During the period of sludge bulking in the unit, there was no trace of nitrification and effluent NH_3-N was about 90 to 95 percent of the influent ammonia nitrogen (106 mg/l). However, by the time the unit came to a more normal condition with regard to settleability and retention of biological solids, traces of nitrification were observed in the effluent.

Phase II

Performance Characteristics of the Extended Aeration Pilot Plant Operating With the "Hydrolytic Assist" at an Organic Loading of 1000 mg/l Glucose + Hydrolysate

Figure 5 shows the performance of the pilot plant during days 24 to 69 while operating with "hydrolytic assist" at substrate concentration of 1000 mg/l glucose + hydrolysate (Table I). The prime aim of preparing hydrolysate was to provide a control over the biological solids concentration by initiating the de-accumulation periods through chemical hydrolysis of portions of the cells prior to their recycle. Every week a 900-ml volume of sludge was withdrawn from the clarifier. The arrows at the top of the figure show the days on which sludge was withdrawn and hydrolyzed. It is seen in this figure that this mode of operation provided for rather good and stable operation from days 28 to 48, i.e., through three sludge withdrawals and refeeding periods. The biochemical removal efficiency was 96 percent based on filtrate COD, and 92 percent based on unfiltered COD. The average biological solids concentration in the effluent during this time was 36 mg/l. The average filtrate COD in

Figure 5. Performance Characteristics of a Hydrolytically-Assisted Extended Aeration Process Pilot Plant From Day 24 to Day 69 of Operation


Si, mg/ℓ
2000
1000
900 mℓ
900 mℓ
900 mℓ
900 mℓ
900 mℓ
900 mℓ
X, mg/ℓ
7000
6000
5000
4000
3000
Se(FIL), mg/ℓ
100
0
Xe, mg/ℓ
150
100
50
0
Se, mg/ℓ
200
150
100
50
NH3-N, mg/ℓ
100
0
NO3-N, mg/ℓ
100
0
24
29
34
39
44
49
54
59
64
69
TIME, DAYS

the effluent was 48 mg/l, and the average unfiltered COD in the effluent was 99 mg/l. The average biological solids concentration in the total system was 6192 mg/l, and the "food" to microorganism ratio was 0.21. Throughout this phase of study, pH 7.2 was maintained in the system.

Between days 46 and 57, biological solids concentration decreased from 6800 mg/l to 3250 mg/l. During this period, the effluent solids concentration rose only slightly. There was a slight rise in the COD of the effluent, and the biochemical efficiency based on filtrate COD also dropped from 96 to 92 percent. The pH was checked frequently to make sure that acid conditions did not develop. However, during the decrease of solids concentration, some froth was formed on the surface in the aeration tank, and it appeared that a portion of the sludge had undergone a gradual lysis. The symptoms were similar to observations made by previous researchers during a period of solid de-accumulation (2). It is very interesting to note that during the "lysis" period, the nitrification in the system increased to 95 percent, and at times, all of the ammonia nitrogen in the influent was converted to NO_3-N. The "food" to microorganism ratio increased from 0.18 to 0.48. From days 49 to 54, the NH_3-N concentration had decreased to essentially trace amounts, and a highly nitrified effluent was being produced. It is significant to note that during operation of the pilot plant even with the "hydrolytic assist" there were periods of biological accumulation and de-accumulation but considerably shorter in duration and lower in magnitude than those which existed without "hydrolytic assist" (2)(3).

Between days 60 and 68, the substrate concentration was increased gradually from 1000 mg/l glucose + hydrolysate to 1500 mg/l glucose + hydrolysate. The biochemical efficiency of the system remained above

96 percent. During this period, the effluent solids concentration increased and there was also a rise in supernatant COD. The food to microorganism ratio varied between 0.48 to 0.28. At the beginning of this new period of solids buildup in the system, the NH_3-N in the effluent increased and NO_3-N decreased gradually to 40 mg/l. The NO_2-N is not plotted in the figure, but there was normally only a trace amount present. The pH in the system was maintained at 7.2 by adding a few drops of potassium hydroxide (N 10) at regular intervals.

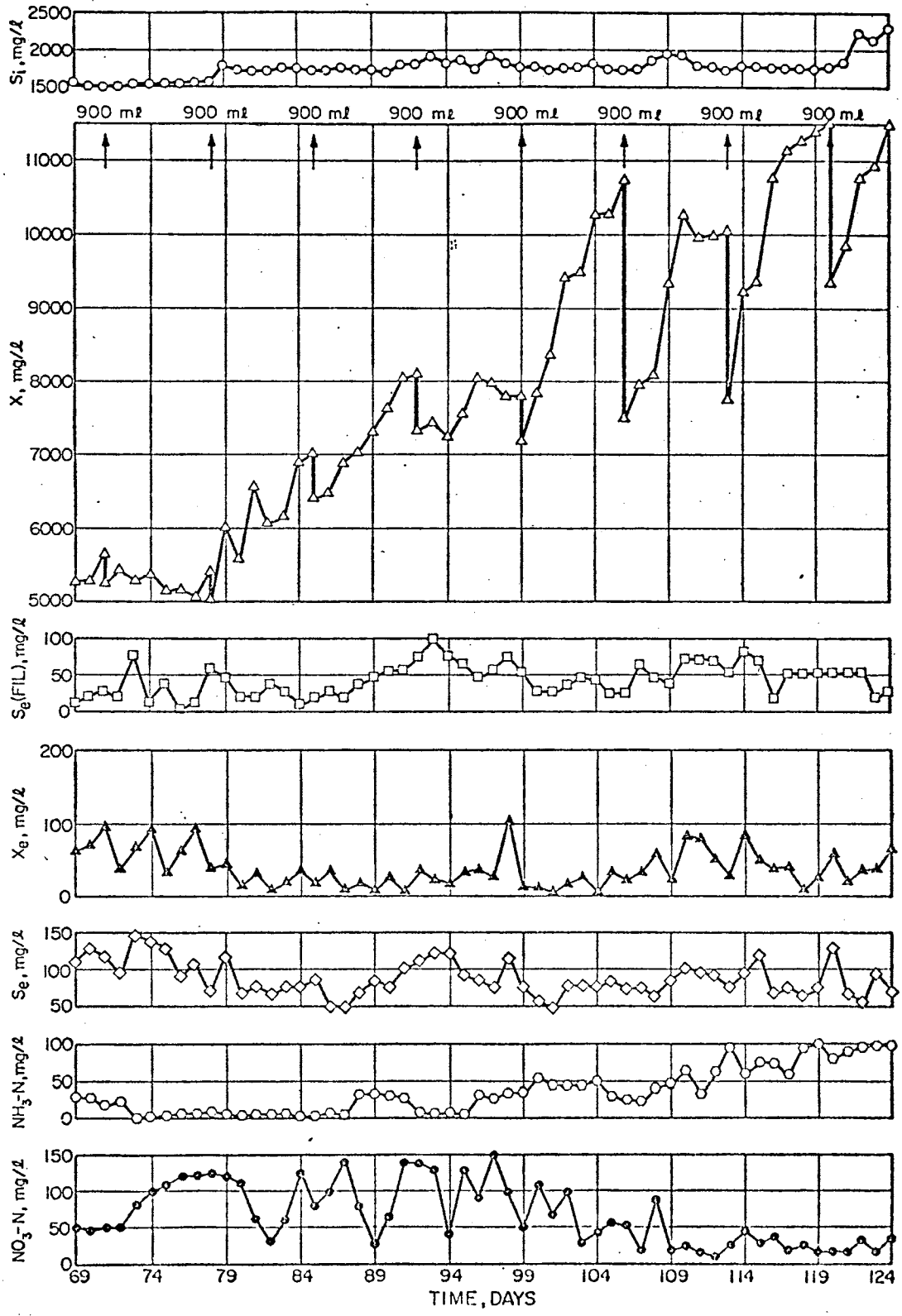
The dissolved oxygen recorded in the aeration tank and settling tank varied between 5 mg/l to 7 mg/l, and zero mg/l to 2 mg/l, respectively. Occasionally, rising sludge was noticed during the periods of high nitrification in the unit. In particular during nitrification, the pH in the system often decreased to pH 6.8 and it was brought back to pH 7.2 by adding a few drops of potassium hydroxide at regular intervals.

Phase III

Performance Characteristics of the Extended Aeration Pilot Plant Operating With the "Hydrolytic Assist" at an Organic Loading of 1500 mg/l Glucose + Hydrolysate

This phase began on day 69. The unit was brought gradually to substrate concentration of 1500 mg/l glucose + hydrolysate (Table II). The performance characteristics are shown in Figure 6. Gradually, after increasing the substrate concentration to 1500 mg/l glucose + hydrolysate, the solids in the system levelled off at approximately

Figure 6. Performance Characteristics of a Hydrolytically-Assisted Extended Aeration Process Pilot Plant From Day 69 to Day 124 of Operation


S_i, mg/ℓ
2500
2000
1500
900 mℓ
900 mℓ
900 mℓ
900 mℓ
900 mℓ
900 mℓ
900 mℓ
900 mℓ
11000
10000
9000
X, mg/ℓ
8000
7000
6000
5000
S_e(FIL), mg/ℓ
100
50
0
200
100
0
X_e, mg/ℓ
150
100
50
S_e, mg/ℓ
100
50
0
NH_3-N, mg/ℓ
150
100
50
0
NO_3-N, mg/ℓ
69
74
79
84
89
94
99
104
109
114
119
124
TIME, DAYS

5200 mg/l (see days 69-78). The effluent solids concentration occasionally increased to 100 mg/l, and there was also a rise in the supernatant COD or effluent COD, but the biochemical efficiency of the system remained above 95 percent based on filtrate COD. The influent NH_3-N was 160 mg/l and effluent NH_3-N was one-fourth that of influent. The NO_3-N was 50 mg/l, and gradually the system produced a highly nitrified effluent.

From days 78 to 92, biological solids concentration increased from 5000 to 8000 mg/l, and the biochemical efficiency of the system remained above 97 percent, based on filtrate COD. Also, as can be seen in the figure, the biological solids concentration in the effluent was small (8 to 30 mg/l) and the unfiltered COD, i.e., the supernatant COD or effluent COD, remained low. Microscopic examination indicated insignificant amount of filamentous organisms. It is recalled that these studies were made at COD:N ratio of 10:1 in the synthetic waste feed, and that additional nitrogen was contained in the hydrolysate. It can be noted from the figure that NH_3-N in the effluent had reached negligible quantity, whereas NO_3-N fluctuated between 50 mg/l to 200 mg/l. It is seen that at times, practically all of the influent nitrogen in the synthetic waste appeared in the effluent as NO_3-N. Sufficient care was always taken to see that the pH did not go below 7.0; rather it was always maintained at 7.3. The dissolved oxygen monitored in the aeration tank and clarifier varied between 5 mg/l to 7.5 mg/l, and zero mg/l to 2 mg/l, respectively.

Between days 92 to 114, the unit operated rather steadily with respect to effluent quality. During this period, the biochemical efficiency in the system remained above 95 percent based on filtrate COD, and the effluent solids concentration was very low. The unfiltered COD

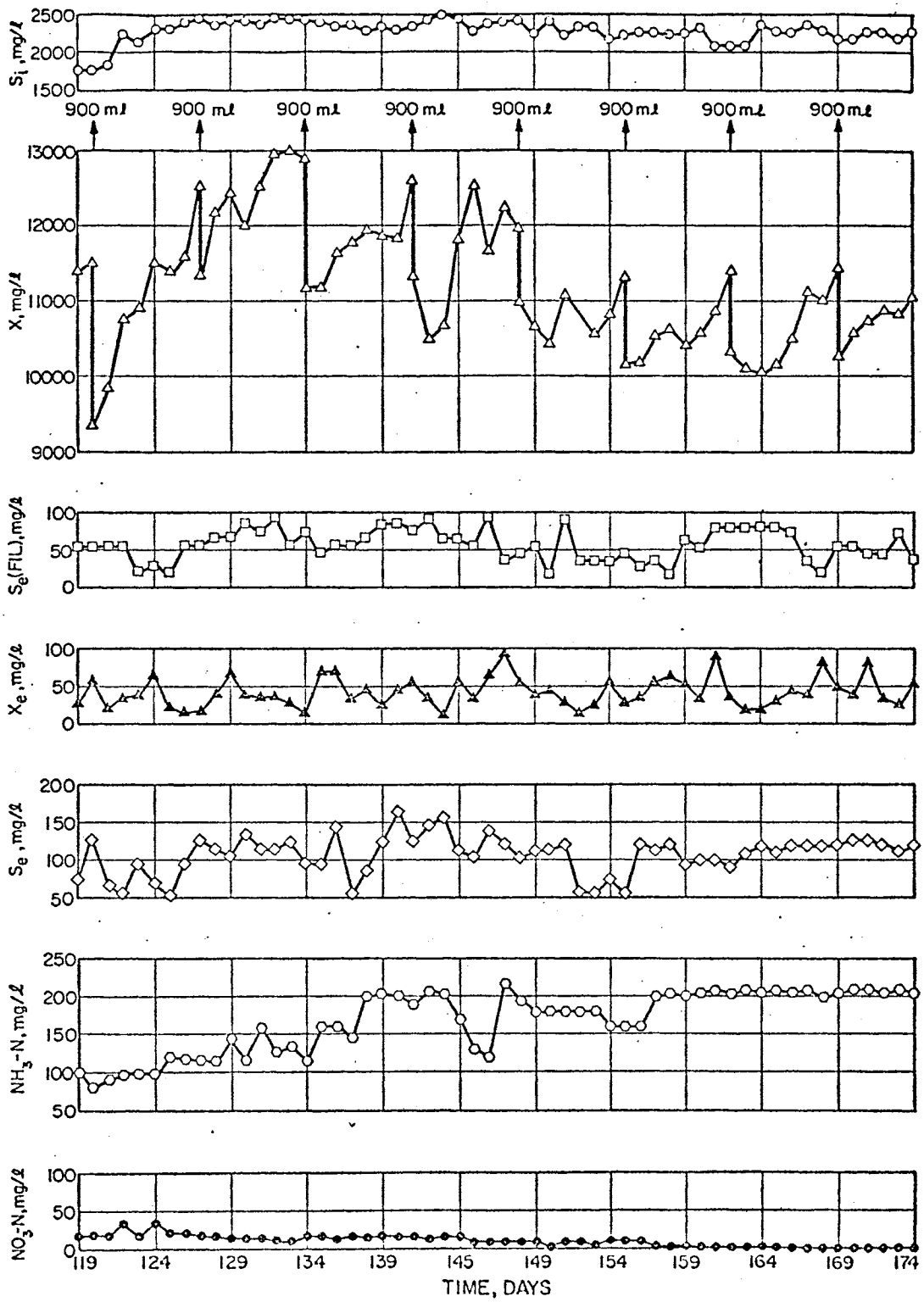
was also low, and in general the operational behavior of the unit was excellent with very good settling characteristics of sludge in the clarifier. At times, the sludge withdrawn for hydrolysis had a very high concentration; for example, on day 106 it was nearly 30,000 mg/l. In general, compaction was good and the solids concentration in the clarifier was approximately four times the concentration in the aeration tank or three times the concentration of the total system. The unit did not exhibit problems such as rising sludge, bulking sludge, or turbid effluent. The color of the effluent in general was light yellow, but unfortunately, the nitrification in the system diminished gradually from 95 percent to 40 percent with respect to influent. The "food" to microorganisms ratio varied between 0.25 to 0.17 in the total system during this period.

Phase IV

Performance Characteristics of the Extended Aeration Pilot Plant Operating With the "Hydrolytic Assist" at an Organic Loading of 2000 mg/l Glucose + Hydrolysate

Studies were also made at an organic loading of 2000 mg/l glucose plus hydrolysate (Table III) in the extended aeration unit. Figure 7 shows the total performance during the period between days 119 and 174. The organic loading was increased gradually from 1500 mg/l glucose + hydrolysate to 2000 mg/l glucose + hydrolysate between days 119 and 122. From days 119 to 134, the biological solids concentration rose from 9300 mg/l to 13,000 mg/l. Weekly withdrawal of 900 ml of sludge from the

Figure 7. Performance Characteristics of a Hydrolytically-Assisted Extended Aeration Process Pilot Plant From Day 119 to Day 174 of Operation


S_i, mg/ℓ
2500
2000
1500
900 mℓ
900 mℓ
900 mℓ
900 mℓ
900 mℓ
900 mℓ
900 mℓ
900 mℓ
X, mg/ℓ
13000
12000
11000
10000
9000
S_e(FIL), mg/ℓ
100
50
0
X_e, mg/ℓ
100
50
0
S_e, mg/ℓ
200
150
100
50
NH_3-N, mg/ℓ
250
200
150
100
50
NO_3-N, mg/ℓ
100
50
0
119
124
129
134
139
145
149
154
159
164
169
174
TIME, DAYS

clarifier and refeeding the hydrolyzed sludge after neutralizing the pH was continued in the usual way as explained previously. The biochemical efficiency of the system remained above 96 percent and also, as can be seen in the figure, the biological solids concentration in the effluent was in general below 50 mg/l; the unfiltered COD, i.e., the supernatant COD (S_e), remained low. The "food" to microorganism ratio varied between 0.16 to 0.22. These studies were also made at COD:N ratio of 10:1. The pH was checked frequently to assure that acid conditions did not develop so that a favorable environment was being maintained for nitrifiers in the system. The NH_3-N concentration in the filtrate effluent increased gradually from 60 mg/l to 130 mg/l, whereas the NO_3-N varied between 40 mg/l and 20 mg/l. Nitrite was present in trace amounts (often less than 0.1 mg/l).

Between days 134 and 154, the biological solids concentration decreased slowly from 13,000 mg/l to 10,810 mg/l, and the biochemical efficiency remained always above 96 percent. Biological solids concentration in the effluent ranged from 6 mg/l to 70 mg/l, and in most cases it was approximately 30 mg/l. The "food" to microorganism ratio varied between 0.19 and 0.22. Also, as can be seen in the figure, there was not much change in unfiltered COD, and it ranged between 100 mg/l and 150 mg/l. The NH_3-N in the effluent varied from 150 mg/l to 200 mg/l, whereas the influent NH_3-N was 212 mg/l. During this period, the NH_3-N in the effluent further decreased from 20 mg/l to 10 mg/l, and the NO_2-N in the effluent was occasionally less than 0.1 mg/l.

From days 154 to 174, biological solids concentration was maintained at approximately 10,500 mg/l, and the unit was in a relatively steady condition during this period. The biochemical efficiency was

always above 96 percent based on filtrate COD. Biological solids concentration in the effluent in general was less than 50 mg/l. The supernatant COD remained low--between 75 mg/l and 125 mg/l. The "food" to microorganism ratio (F/M) was maintained at approximately 0.21.

It is seen that after increasing the organic loading, the dominant form of effluent nitrogen changed gradually from NO_3-N to NH_3-N. Also, it is noted that at times, practically all of the influent nitrogen appeared in the effluent as NH_3-N.

Studies on Acid Hydrolysis

The general operational procedure involving periodic withdrawal of sludge, hydrolysis, and recycling of hydrolysate to the aeration chamber was shown in Figure 3. The cell hydrolysate was prepared by partial hydrolysis of the sludge withdrawn from the clarifier. The sludge was acidified to pH 1.0 with H_2SO_4 (36 N) and autoclaved usually for five hours at 15 psi, 121^{o}C. This hydrolyzed sludge was neutralized to pH 7 with KOH (10 N) to obtain hydrolysate for feeding to the unit. From an engineering standpoint, it would be wise to determine the autoclaving period for maximum solubilization of the biomass. Studies were made at various autoclaving periods holding other operational procedures (pH, temperature, and pressure) as before; biological solids concentration, unfiltered COD, and filtrate COD for various periods of autoclaving were determined. As an example, the operational results obtained from the hydrolysis of sludge on day 113 are shown in Table V. Solubility of the biomass based either upon COD or upon biological solids concentration was not affected to any great extent by the period of autoclaving. Many other experiments gave similar results. In general, the solubility of

the biomass ranged between 80 to 90 percent (based on biological solids) after five hours of autoclaving. This finding created an interest to find the percentage solubility for 1, 2, 3, 4, and 5 hours of autoclaving. Therefore, on day 155, hydrolysis of the sludge was conducted and results monitored at 1, 2, 3, 4, and 5 hours, as shown in Table VI.

TABLE V

HYDROLYSIS CHARACTERISTICS OF A HYDROLYTICALLY-ASSISTED EXTENDED AERATION ACTIVATED SLUDGE PILOT PLANT ON DAY 113

Autoclave Time, Hours	0	5	10	15	20	25	30
Unfiltered COD, mg/l	23,400	23,400	23,800	24,500	26,000	26,800	27,500
Filtrate COD, mg/l	≈0	18,100	18,500	18,900	20,000	20,400	20,800
Percent Solubility Based on COD	≈0	77.4	77.7	77.1	76.9	76.1	75.6
Solids, mg/l	20,204	1916	1952	1968	2008	2748	2928
Percent Solubility Based on Solids		90.8	91.2	91.3	91.5	88.5	88.3

In this instance it is seen that there was, regardless of the

method of calculating solubility due to hydrolysis, a small but signigicant incirease from one to five hours. These results indicate that there appears to be very little to be gained in elongating the hydrolysis period beyond five hours, but perhaps it could be shortened somewhat.

TABLE VI

HYDROLYSIS CHARACTERISTICS OF A HYDROLYTICALLY-ASSISTED EXTENDED AERATION ACTIVATED SLUDGE PILOT PLANT ON DAY 155

Autoclave Time, Hours	0	1	2	3	4	5
Unfiltered COD, mg/l	19,000	19,000	20,600	20,600	21,300	21,700
Filtrate COD, mg/l	0	13,800	14,600	15,000	15,800	16,500
Percent Solubility Based on COD	0	72.6	70.8	72.8	74.2	76.0
Solids, mg/l	14,540	3,272	2,588	2,388	2,416	2,176
Percent Solubility Based on Solids	-	78.0	83.3	85.4	85.4	87.3

CHAPTER V

DISCUSSION

The results obtained during Phase I of the study (Figure 4) provide strong supportive evidence that the "hydrolytic assist" can be used effectively to alleviate bulking conditions. One of the important requirements for proper operation of the activated sludge process depends upon the separation of the microbial population from the purified waste in the sedimentation tank. During the early phase, filaments were not being successfully decreased by natural autodigestion. During the period of filamentous bulking, the supernatant liquid was very clear, but the sludge settling was poor and there was occasional loss of solids into the effluent. Many causes for the predominance of filamentous organisms in activated sludge have been reported (18)(20)(21). A pH drop was not the cause in the present case, because pH was maintained at 7.1 and nitrification was not taking place in the unit at that time. There are various ways to prevent the growth of filamentous organisms (21)(23). In the present study, weekly hydrolysis of portions of the sludge from the system did help to rid it of the undesirable organisms. The hydrolysate prepared from filamentous organisms fed to the unit enhanced the growth of more desirable organisms which would settle readily. The COD:N ratio was maintained at 10:1 throughout these studies; thus, the high nitrogen concentration did not help to maintain predominance of species other than filamentous forms. It

has been observed in other studies (29) that an increase in ammonia nitrogen did not tend to help shift predominance from filamentous to individual or flocced microorganisms. Acid hydrolysis dissolved the filamentous organisms; thus, the hydrolyzability of the filamentous organisms was similar to that of the other heterogeneous populations (33). After refeeding the hydrolysate, the settling in the clarifier was much better, and non-filamentous species and protozoa were noted. Results from this investigation were encouraging and indicate that from an engineering point of view, the "hydrolytic assist" can be used successfully for getting rid of undesirable organisms from an activated sludge process. This means of ridding the system of filamentous organisms was also tried with success by Gaudy, Yang, and Obayashi (3) and by Scott (33). The results of the present study indicate that the hydrolysate prepared from filamentous organisms can be used as a substrate by other microbial populations more readily than by the filamentous forms themselves, since there was an early change in the predominance of species in the system.

In general, extended aeration processes can be expected to produce a nitrified effluent and the prime aim of this experimental investigation was to determine whether the extended aeration process can produce a nitrified effluent at higher organic loadings. Figure 5 showed the overall performance during the period of substrate concentration at 1000 mg/l glucose + hydrolysate. A good balanced condition of operation with respect to biological solid was obtained during days 28 to 48. During that three-week period the effluent was not appreciably nitrified in the early period. The unit produced highly nitrified effluents during the latter part of the steady state period. Jones and Patni (39)

recently reported the removal of large amounts of nitrogen from a full scale oxidation ditch under similar environmental conditions. The pH, temperature, dissolved oxygen distribution of the mixed liquor, and the daily load suggested that nitrogen removal was mainly by a nitrification-denitrification sequence. Between days 47 to 57, the steep falling gradient of biological solids concentration in the system clearly suggests autolysis even when the regular weekly hydrolysis was being continued. The more interesting point during this period was the production of highly nitrified effluent. During autolysis, the "food" to microorganism ratio varied between 0.18 to 0.35. COD removal efficiency was, in general, above 93 percent throughout the period for a feed of approximately 1275 mg/l and an aeration chamber detention time of 16 hours. It is interesting to note that even at this high loading the sludge did not steadily accumulate, but there was a cycle of decreasing biological solids concentration followed by a succeeding period of solids accumulation. During this period of decreasing biological solids concentration, no gross leakage of COD in the effluent was observed. This decrease in the solids concentration cannot be attributed to adverse environmental causes such as temperature, pH, organic loadings, and dissolved oxygen in the system. These cells were not lost in the effluent, but were decreased due to a period of accelerated autodigestion (2). The system produced rather a well nitrified effluent during this period of operation, which is readily seen in Figure 5.

Days 79 to 119 (Figure 6) comprised the third phase of the study, and a feed of approximately 1790 mg/l (1500 mg/l glucose + hydrolysate) was applied. Biological solids concentration gradually increased from 5000 mg/l to 11,000 mg/l, and the biochemical efficiency of the system

remained above 94 percent based on unfiltered COD. The NO_3-N varied between 50 mg/l and 150 mg/l for an influent NH_4-N of 159 mg/l based upon the synthetic waste; i.e., at times, practically all of the influent nitrogen appeared in the effluent as nitrate nitrogen. It should be noted that COD:N ratio was 10:1 based upon synthetic waste, i.e., glucose concentration). Analyses of hydrolysate for nitrogen were not made because the hydrolysate was considered to be part of the sludge, not the feed. Also, since the system proved excellent purification efficiency, only traces of organic nitrogen could be expected in the effluent, and hence organic nitrogen analysis was not made.

Yang and Gaudy (29) reported that there was a greater retention of nitrogen in the sludge and less reuse of the nitrogen at COD:N = 20:1 than during operation at COD:N = 30:1. Normally for the treatment of nitrogen-deficient waste, less nitrogen supplementation is recommended for the extended aeration process when compared to that of a conventional type of process.

During the study, an interesting observation was made regarding the "location" of the nitrification reactions. Between days 79 and 84 the sludge showed a slight rising tendency, although the effluent remained excellent. Periodic DO determinations of the effluent show that one mg/l DO was present, and as can be seen in Figure 6, the NO_3-N concentration had decreased. It was felt that it might be possible for denitrification in the settling chamber to be the real cause for the apparent lowering of nitrification. Accordingly, it was decided to determine the nitrate concentration in the aeration chamber as well as the settling tank. A higher NO_3-N concentration in the aerator than in the settling chamber could be taken as evidence that the system was

still nitrifying but that denitrification was taking place in the settling tank. However, the results of the first comparative analysis (on day 84) showed the opposite was true; i.e., the NO_3-N concentration was higher in the settling tank. This condition was observed repeatedly on five subsequent occasions between days 84 and 92. It is possible that the high degree of treatment (no or little organic substrate in the mixed liquor) coupled with the higher biological solids concentration in the settling chamber are indicative of more favorable conditions and number of nitrifiers in the clarifier than in the aeration tank. Conditions under which a highly nitrified effluent can be produced in a biological treatment process have been studied by a number of investigators, but there are differences of opinion regarding the governing factors. For the present investigation, the DO in the settling tank varied between zero mg/l to 2 mg/l, while it ranged between 5 mg/l and 7.5 mg/l in the aeration tank. The pH was maintained at 7.3 in both reactors. Periodic withdrawal of a fixed 900-ml volume of highly concentrated sludge from the clarifier was continued regularly. The nitrification gradually reduced in the system and there was from day 109 to 124 approximately 40 mg/l NO_3-N in the effluent for an influent NH_3-N of 159 mg/l.

The results of the study in Phase IV (Figure 7) for a feed of 2000 mg/l glucose provide evidence for high performance of an extended aeration process with "hydrolytic assist" at an extremely high loading. At this higher organic loading, the nitrification in the system diminished very much when compared to that of the lower organic loadings presented before, and it may be concluded that while organotrophic performance was excellent, the system cannot be expected to nitrify readily at such

a high loading. The hydrolyzed solids in the system approximated a roughly balanced condition at 10,500 mg/l (Figure 7) and the biochemical efficiency was above 95 percent throughout, based on filtrate COD.

The studies made on acid hydrolysis show that the solubility of the biomass was above 70 percent (Table VI) after one hour of autoclaving, and it increased a small amount after five hours of autoclaving. Also, as can be seen from Table V, the solubility of the biomass of the hydrolysate did not change appreciably between five hours and 30 hours. Perhaps a mild condition of acid hydrolysis, e.g., 15 psi, 121^{o}C for one to two hours would be sufficient for control of the autodigestion process. Such studies might prove to be useful.

CHAPTER VI

SUMMARY AND CONCLUSIONS

Before listing specific conclusions regarding this particular investigation, it is appropriate to discuss a general conclusion regarding the practical utility and engineering feasibility of the extended aeration process.

Many small localities are not served by municipal treatment plants; septic tank systems are generally used for the treatment and disposal of wastes. Because of such treatment (or lack of it), surface and ground waters often become polluted, leading to unsanitary conditions. The present awareness of environmental pollution control has stimulated interest in various alternate methods of wastewater treatment to assure an effluent of good quality before discharge to water bodies. Everyone is desirous of having treatment plants that are easily operated and serve their intended purpose over a long period of time and with little maintenance. In this context, extended aeration activated sludge processes offer advantages.

The volume of sludge produced is significantly reduced because of "auto-oxidation." As a result, sludge treatment does not pose a serious problem. The process can be expected to produce a nitrified effluent. The long aeration period and low BOD loading can enhance presence of abundant protozoa, rotifers, metazoa, etc., which seem to have beneficial effects on flocculation and clarification for efficient

separation of the mixed liquor (40). The recently introduced "hydrolytic assist" offers an engineering control which may be employed to aid autodigestion when needed. Furthermore, the work on total oxidation which was accomplished previously in these laboratories, erase doubts regarding the theoretical validity of the concept. Thus, it is felt that for small communities, the process offers considerable hope for accomplishment of water pollution control. The present investigation at high organic loadings also provides insight into the applicability of the process to high strength industrial wastes. Based upon the present study, the following specific conclusions seem warranted:

1. The "hydrolytic assist" has proven successful as an engineering control for disposing of undesirable organisms from an activated sludge process. The hydrolysate prepared from filamentous organisms can be used as a substrate by other microbial populations.

2. Highly nitrified effluents can be produced in a hydrolytically-assisted extended aeration process up to an organic loading of 1500 mg/l.

3. Excellent treatment for removal of organic matter is possible in the extended aeration process with the "hydrolytic assist" as an engineering control for high strength waste, e.g., 2000 mg/l.

4. The present investigations add further evidence that organic loading can be correlated with the degree of nitrification.

5. It may be possible to reduce the period for acid hydrolysis at 15 psi, 121^{o}C to one to three hours without impairing the benefit one obtains, by using the "hydrolytic assist" to control biological solids concentration.

CHAPTER VII

SUGGESTIONS FOR FUTURE WORK

The results of the present investigation have provided supportive evidence for the operational feasibility of the hydrolytically-assisted extended aeration process for treating organic wastes. There are, however, certain aspects of the work which warrant further investigation, and some of these are:

1. Instead of weekly withdrawal, a quarter-yearly or half-yearly withdrawal of sludge concentration may give better nitrification. Hence, it would be useful to observe purification and nitrifying characteristics of a system for which sludge was hydrolyzed only as required to prevent solid from building up too high in the settling chamber.

2. Improved nitrification at high organic loading in the extended aeration process might be attained by employing two stages of reactors --one for carbon removal, and another for nitrification.

3. Further experimental studies of hydrolysis conditions, e.g., different pressures and temperatures for sludges of various origins would be of great value from an engineering point of view, especially application to treatment of industrial wastes.

4. Further experimental data on the chemical requirement for acidification and neutralization of the different sludges to be hydrolyzed would assist greatly in projecting costs for operating such a

system. This would be of interest for the industrial use of the hydrolytically-assisted process at full scale level.

5. Study the possible saving in phosphorous supplementation due to the reuse of phosphorous enhanced by the "hydrolytic assist" may prove useful in cost analysis for treatment of some industrial wastes.

BIBLIOGRAPHY

1. Ramanathan, M., Gaudy, A. F. Jr., and Ragthaidee, W., "Responses Extended Aeration Activated Sludge to Quantitative Shock Loads." Proceedings, 19th Oklahoma Industrial Waste and Pollution Control Conference, Stillwater, Oklahoma (1968).

2. Gaudy, A. F. Jr., Ramanathan, M., Yang, P. Y., and DeGeare, T. V., "Studies on the Operational Stability of the Extended Aeration Process." Journal Water Pollution Control Federation, 42, 165-179 (1970).

3. Gaudy, A. F. Jr., Yang, P. Y., and Obayashi, A. W., "Studies on the Total Oxidation of Activated Sludge With and Without Hydrolytic Pretreatment." Journal Water Pollution Control Federation, 43, 40-54 (1971).

4. Obayashi, A. W., and Gaudy, A. F. Jr., "Aerobic Digestion of Extracellular Microbial Polysaccharides." Journal Water Pollution Control Federation, 45, 1584-1594 (1973).

5. Waste Water Engineering: Collection, Treatment, Disposal. Metcalf and Eddy, Inc., 636-637. McGraw-Hill Book Company: New York (1972).

6. Porges, N., Repinsky, J. B., Headler, N. C., and Hoover, S. R., "Biochemical Oxidation of Dairy Wastes. I. Methods of Study." Sewage and Industrial Wastes, 22, 318-325 (1951).

7. Hoover, S. R., Jasewicz, L., Pepinsky, J. B., and Porges, N., "Assimilation of Dairy Wastes by Activated Sludge." Sewage and Industrial Wastes, 22, 318-325 (1950).

8. Hoover, S. R., Jasewicz, L., and Porges, N., "Biochemical Oxidation of Dairy Wastes. IV. Endogenous Respiration and Stability of Aerated Dairy Waste Sludge." Sewage and Industrial Wastes, 24, 1144-1149 (1952).

9. Thayer, P. M., "New Design for an Activated Sludge Plant to Treat Milk Wastes." Proceedings, 6th Industrial Waste Conference, Purdue University, Lafayette, Indiana, 171-175 (1951).

10. Thayer, P. M., "Design Features of Activated Sludge Plant to Treat Milk Wastes." Proceedings, 7th Industrial Waste Conference, Purdue University, Lafayette, Indiana, 509-517 (1952).

11. Symons, J. M., and McKinney, R. E., "The Biochemistry of Nitrogen in the Synthesis of Activated Sludge." Sewage and Industrial Wastes, 30, 874-890 (1959).

12. Busch, A. W., and Myrick, N., "Food Population Equilibria in Bench-Scale Biooxidation Units." Sewage and Industrial Wastes, 30, 874-890 (1959).

13. McCarty, P. L., and Broderson, C. F., "Theory of Extended Aeration Activated Sludge." Journal Water Pollution Control Federation, 34, 767-789 (1962).

14. Washington, D. R., Hetling, L. J., and Rao, S. S., "Long Term Adaptation of Activated Sludge Organisms to Accumulated Sludge Mass." Proceedings, 19th Industrial Waste Conference, Purdue University, Lafayette, Indiana, 655-666 (1965).

15. Sawyer, C. N., "Milestones in the Development of the Activated Sludge Process." Journal Water Pollution Control Federation, 37, 151-162 (1965).

16. Yang, P. Y., and Gaudy, A. F. Jr., "Control of Biological Sooids Concentration in the Extended Aeration Process." Presented at the 28th Industrial Waste Conference, Purdue University, Lafayette, Indiana, May 1-3 (1973).

17. Tara, Singh, and Patterson, James W., "Improvement of the Aerobic Sludge Digestion Process Efficiency." Proceedings, 45th Annual Conference, Water Pollution Control Federation, Atlanta, Georgia (1972).

18. Heukelekian, H., and Weisberg, E., "Bound Water and Activated Sludge Bulking." Sewage and Industrial Wastes, 28, 558-574 (1972).

19. Finstein, M. S., and Heukelekian, H., "Filamentous Microorganisms and the Bulking of Activated Sludge." Proceedings, 20th Industrial Waste Conference, Purdue University, Lafayette, Indiana, 175-181 (1965).

20. Farquhar, G. J., and Boyle, W. C., "Occurrence of Filamentous Microorganisms in Activated Sludge." Journal Water Pollution Control Federation, 43, 779-788 (1971).

21. Pipes, Wesley O., "Bulking of Activated Sludge." In Advances In Applied Microbiology, 9, 184-234 (1967).

22. Gaudy, Elizabeth, and Wolfe, R. S., "Composition of an Extracellular Polysaccharide Produced by Sphaerotilus natans." Appl. Microbiol., 10, 200-205 (1962).

23. Cole, Charles A., Stamberg, J. B., and Bishop, D. F., "Hydrogen Peroxide Cures Filamentous Growth in Activated Sludge." Journal Water Pollution Control Federation, 45, 829-836 (1973).

24. Wild, Harry E. Jr., Sawyer, Clair, N., and McMahan, Thomas C., "Factors Affecting Nitrification Kinetics." Journal Water Pollution Control Federation, 43, 1845-1854 (1971).

25. Ganczarczyk, Jerzy, "Nitrogen Transformation in Activated Sludge Treatment." Jour. San. Engr. Div., 97, 247 (1971).

26. Beckman, W. J., Avendt, R. J., Mulligan, J. J., AND Kehrberger, G. J., "Combined Carbon Oxidation-Nitrification." Journal Water Pollution Control Federation, 44, 1916-1931 (1972).

27. Downing, A. L., Painter, H. A., and Knowledge, G., "Nitrification in the Activated Sludge Process." Journal of the Institute for Sewage Purification, Pt. 2, 130-158 (1964).

28. Haug, Roger T., and McCarty, Perry L., "Nitrification With Submerged Filters." Journal Water Pollution Control Federation, 44, 2086-2102 (1972).

29. Yang, P. Y., and Gaudy, A. F. Jr., "Nitrogen Metabolism in Extended Aeration Processes Operated With and Without Hydrolytic Pretreatment of Portions of the Sludge." Biotechnology and Bioengineering, XVI, 1-20 (1974).

30. Drews, R. J. L. C., Malan, W. M., Meiring, P. G. J., and Moffat, B., "The Orbal Extended Aeration Activated Sludge Plant." Journal Water Pollution Control Federation, 44, 221-231 (1972).

31. Jenkins, D., and Garrison, W. E., "Control of Activated Sludge by Mean Cell Residence Time." Journal Water Pollution Control Federation, 40, 1905-1919 (1968).

32. Sawyer, Clair N., and McCarty, Perry L., Chemistry for Sanitary Engineers. 2nd ed., 70-73. McGraw-Hill Book Company: New York (1967).

33. Scott, David, "Studies on the Performance of the Hydrolytically-Assisted Extended Aeration Process as a Means of Treating Soluble Organic Waste Materials." PhD Thesis, Oklahoma State University, Stillwater, Oklahoma (1973).

34. Precision Galvanic Cell Oxygen Analyzer. Publication TS-68850, Precision Scientific Company, Chicago, Illinois (1961).

35. Standard Methods for the Examination of Water and Wastewater. 13th ed. American Public Health Association: New York (1971).

36. Ecker, R. E., and Lockhart, W. R., "Specific Effect of Limiting Nutrients on Physiological Events During Culture Growth." Journal Bacteriology, 82, 511-516 (1961).

37. Yang, Ping-Yi, "Studies on Extended Aeration Activated Sludge and a Modification of the Process Employing Chemical Hydrolysis of Portions of the Return Sludge." PhD Thesis, Oklahoma State University, Stillwater, Oklahoma (1972).

38. Eckenfelder, W. Wesley, Jr., "Theory of Biological Treatment of Trade Wastes." Journal Water Pollution Control Federation, 39, 240-250 (1967).

39. Jones, P. H., and Patni, N. K., "Nutrient Transformations in a Swine Waste Oxidation Ditch." Journal Water Pollution Control Federation, 46, 366-379 (1974).

40. Calaway, W. R., "The Metazoa of Waste Treatment Processes. Rotifers." Journal Water Pollution Control Federation, 40, R412-422 (1968).

VITA

Kommu Suryanarayana Murthy

Candidate for the Degree of

Master of Science

Thesis: OPERATIONAL PERFORMANCE AND NITRIFYING CHARACTERISTICS OF A HYDROLYTICALLY-ASSISTED EXTENDED AERATION PROCESS AT HIGH ORGANIC LOADINGS

Major Field: Bioenvironmental Engineering

Biographical:

Personal Data: Born in Andhra Pradesh, India, November 11, 1935, the son of Kommn Sreeramulu and Kommn Subbamma Garu. Married, spouse, Lakshim Suseela; two children: Sandhya Lakshmi and Chandra Sekhar.

Education: Graduated from Board High School, Kaikalur Andhra Pradesh, India, in March, 1951; received Intermediate Science Certificate in Mathematics, Physics, and Chemistry; Bachelor of Engineering (Civil) from Osmania University, India; completed requirements for the Master of Science degree at the Oklahoma State University, Stillwater, Oklahoma, in May, 1974.

Recipient of the Graduate Excellence Award, the Oklahoma State University, 1973.

Professional Experience: Program executive, Nagarjuna Sagar project (Public Works Department), 1955-1957; Faculty Staff member, Civil Engineering Department, Osmania University, India, 1957-1973; Graduate Research Assistant, Oklahoma State University, Bioenvironmental Engineering laboratories, 1973-1974.

Membership in Professional Societies: Institution of Engineers (India); Water Pollution Control Federation; American Society of Civil Engineers.